

Using of polymeric materials to defeat of lightly armored and easily vulnerable targets. Mathematical modeling

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Abstract. The article deals with the possibility of increasing the damaging effects of small-caliber artillery ammunition in the fuel tanks of aircraft and helicopters. A comparison of the results of the calculation of the probability of the incendiary effect of strikers based on fluoropolymers on diesel fuel was made. The calculations of the probabilities of fuel ignition by the method of 'Fragmented criterion'. As a result of the calculations, it was revealed that this method is not suitable for this type of problem statement. A combined methodology has been developed for calculating the probability of fuel ignition, taking into account the ongoing chemical reaction between fluoropolymers and aluminum. All components of the passing heat release process are taken into account - the impactor deformation energy, the impactor braking energy in the fuel, the chemical energy of the reaction undergoing. The energy of the ongoing chemical reaction was taken into account using thermochemistry methods.

1. Introduction

In modern combat, small-caliber barrel artillery is highly effective in fighting both with the weakly protected and lightly armored vehicles. In connection with the recent active use of assault and tactical aviation and helicopters against enemy vehicles, the development and improvement of small-caliber barrel artillery ammunition has become particularly necessary. The effectiveness of the impact on aviation of small-caliber ammunition is the sum of the total number of hits that ultimately lead to the disruption of the life support systems and the functioning of the aircraft.

From the physical factors affecting important functional units of airplanes and helicopters, an incendiary effect is of great interest.

Consequently, the task of creating a new type of small-caliber ammunition, possessing not only the necessary specific energy for breaking through an obstacle, but also the subsequent incendiary over-obstacle effect, which can lead to the destruction of an aviation target, becomes urgent.

2. Evaluation of incendiary actions by the method of 'Fragmentary criterion'

One of the most common ways to assess the incendiary effect of fragments, damaging elements and bullets is the method of evaluation by the 'Fragmentary Criterion' [1].

When assessing the probability of fuel ignition by this method, the impact impulse of a fragment is calculated:

$$i = 0.000204 \cdot m^{1/3} \cdot v \quad (1)$$



where m is the mass of the fragment, g; v is the velocity of the fragment, m/s.

With a specific impulse $i \leq 0.16$, the probability of ignition is zero. With a specific impulse $i \geq 2.5$, the probability of fuel ignition is close to unity. Analyzing the source data for the specific impulse laid down in the 'Fragmentary criterion' method, an approximation dependence to determine the probability of fuel ignition was obtained:

$$p = 1 + 1.08 \cdot e^{-4.16i} - 1.96 \cdot e^{-1.46i} \quad (2)$$

The dependence of the probability of fuel ignition on the kinetic energy (Ek) is shown in Figure 4. However, when using the fragmentation criterion, all dependencies were built on the basis of the calculated specific impulse, which depends on the mass of the fragments and the initial interaction velocity, without taking into account the additional energy released during the chemical reaction, between the fluoroplastic and aluminum, which in turn significantly affects ignition of diesel fuel.

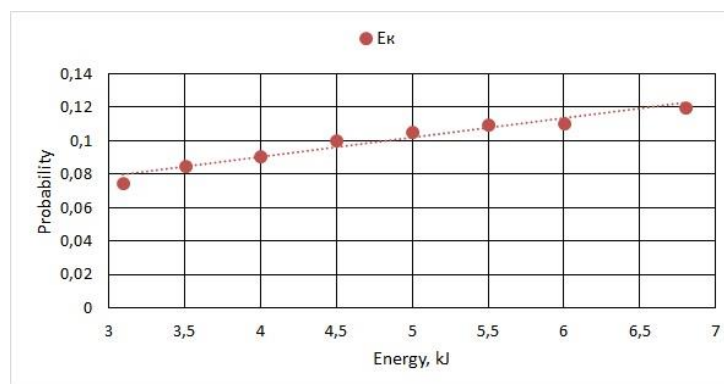


Figure 1. The dependence of the ignition probability from energy.

3. Evaluation of incendiary actions by the method of 'Energy balance'

To assess the effect of a chemical reaction on the ignition of diesel fuel in the fuel tanks, an analysis allowing to estimate the amount of energy released in the process of a chemical reaction spent on heating diesel fuel to a self-ignition temperature was carried out.

As a result, two types of simplified models were obtained: assembly No. 1 and assembly No. 2 (see Figure 2 a and Figure 2 b). The total mass of the striker was 9 grams, in accordance with the conditions of the experiment. To evaluate possible reactions, the mass of fluoroplastic and aluminum in the assemblies ranged from 1 to 8 grams.

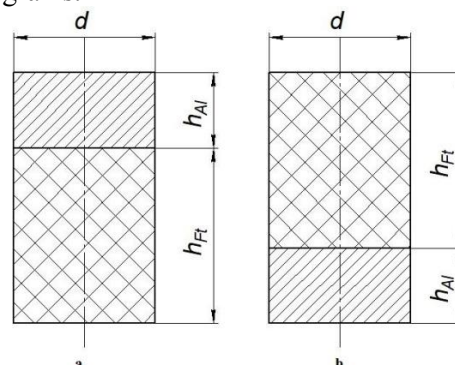


Figure 2. Striker structures for mathematical calculations.

The energy expended on heating diesel fuel while the striker is moving inside the fuel tank will consist of 3 components:

$$E_{st} = E_{react} + E_{def} + E_{dec} \quad (3)$$

where E_{react} – energy released by a chemical reaction, kJ;
 E_{def} – energy released as a result of deformation of a striker, kJ;
 E_{dec} – energy released as a result of deceleration the striker in the fuel, kJ.

The deformation energy of the impactor is determined depending on the relative deformation of the head part of the impactor ε and the dynamic yield strength of the material σ_{df}^* :

$$E_{def} = 0.95 \cdot \frac{S_{mid} \cdot \sigma_{df}^* \cdot \varepsilon}{T^*} \quad (4)$$

where S_{mid} – area of midsection, m²;
 T^* – coefficient of conversion of mechanical energy into heat, kJ.

The analysis performed for various configurations of the striker assemblies shows that the effect of deformation energy on the total energy of the striker is less than 1 %, and is not taken into account in further calculations. Probably, such a low value is associated with a short time of the process of movement of the striker in the fuel (about 10–15 μ s), which is clearly not enough for the process of heat transfer from the striker to the fuel.

The deceleration energy of the striker can be calculated from the equations of motion of the striker in the fluid. At the moment of penetration of the striker into inside of the fuel tank, a certain velocity field will appear in the entire volume of the fluid, and the initial velocity of the striker v_{fmax} will be less than the impact velocity of the striker with the liquid v_c . The value of v_c is determined by the method of N E Zhukovsky. The conservation law for the moment of impact can be written as:

$$(m + m_0) \frac{dv_f}{dt} = mg - \rho_{DF} g V - c_x \frac{\rho_{DF} V_f}{2} S_{mid} \quad (5)$$

where m_0 – the added mass, kg;
 v_f – striker velocity into inside of fuel tank at every moment in time, m/s;
 c_x – impactor drag coefficient, kgm/s²;
 ρ_{DF} – density of diesel fuel, kg/m³;
 V – striker volume, m³;
 g – coefficient of gravity, m/s².

The initial v_{fmax} and the limiting v_{lim} velocity of a striker in a fluid is defined as:

$$v_{fmax} = v_c \left(1 + \frac{m_0}{m} \right)^{-1}, \quad v_{lim} = \sqrt{\frac{2(mg - \rho g V)}{c_x \cdot \rho \cdot S_{mid}}} \quad (6)$$

The initial impact velocity of the striker with the fluid is determined on the basis of the balance of the kinetic energy of the striker:

$$v_c = \sqrt{2E_{res}/m} \quad (7)$$

where E_{res} – residual energy of the striker, calculated as the difference between the initial energy of the striker and the energy expended on the destruction of the target at the specific energy of destruction of the target equal to $E_{sp} = 766.67$ J/cm² [1].

The value of the added mass can be determined by the coefficient of the added mass, which is a function of the elongation of the impactor and its volume:

$$m_0 = \mu_0 \cdot \rho_{DF} \cdot V \quad (8)$$

where μ_0 – the coefficient of the added mass.

The coefficient of the added mass was determined by the method of approximation of tabular data for a fluid with a density of 800...1000 kg/m³ [2]:

$$\mu_0 = 0.5187 \cdot \lambda^{-1.342} \quad (9)$$

where λ – the striker relative elongation.

Graphs of the distribution of the added mass for assemblies No. 1 and No. 2, depending on the mass of the fluoroplastic, are presented in Figure 3.

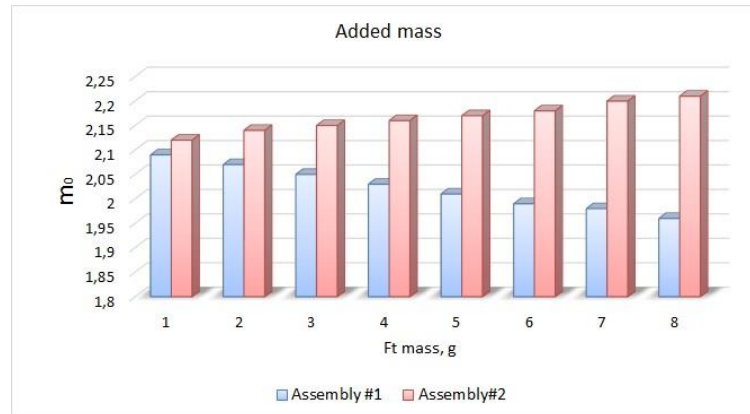
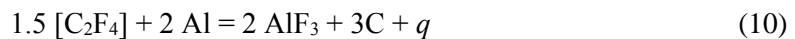


Figure 3. The distribution of the added mass of diesel fuel.

The evaluation of the heat q of the fluoroplastic reaction with aluminum was carried out by thermochemistry [3–6]:

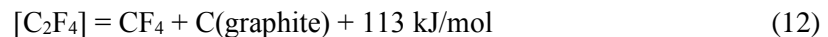


from where

$$q = 1.5 \Delta H_f([\text{C}_2\text{F}_4]) + 2 \Delta H_f(\text{Al}) - 2 \Delta H_f(\text{AlF}_3) - 3 \Delta H_f(\text{C}) \quad (11)$$

where ΔH_f is the molar enthalpy ($\Delta H_f(\text{Al}) = \Delta H_f(\text{C}) = 0$; $\Delta H_f(\text{AlF}_3) = -1490 \text{ kJ/mol}$; $\Delta H_f([\text{C}_2\text{F}_4])$ is the unknown quantity).

So, use the well-known reaction:



From here:

$$\Delta H_f([\text{C}_2\text{F}_4]) = 113 + \Delta H_f(\text{C}) + \Delta H_f(\text{CF}_4) \quad (13)$$

Since $\Delta H_f(\text{C}) = 0$, $\Delta H_f(\text{CF}_4) = -907 \text{ kJ/mol}$, then $\Delta H_f([\text{C}_2\text{F}_4]) = 113 - 907 = -794 \text{ kJ/mol}$.

Then, the heat of reaction of fluoroplastic with aluminum will be equal to:

$$q = 1.5 (-794) + 2 \times 1490 = 1789 \text{ [kJ/2 mol AlF}_3\text{]} \quad (14)$$

Thus, when the fluoroplastic interacts with aluminum, heat $q = 895 \text{ kJ/mol}$ is released.

The molar mass of aluminum in the reaction $M(\text{Al}) = M_r(\text{Al}) \cdot 2 = 53.96 \text{ g/mol}$, the molar mass of the fluoroplastic in the reaction $M(\text{Ft}) = M_r(\text{Ft}) \cdot 1.5 = 798.525 \text{ g/mol}$, where $M_r(\text{Al})$ and $M_r(\text{Ft})$ is the molecular weight of aluminum and fluoroplastic, respectively.

Then, it is necessary to find the number of moles of a substance which, after being introduced into the wall of the fuel tank, enter into a chemical reaction. The number of moles of aluminum and moles of fluoroplastic capable of reacting is defined as the ratio of the mass of aluminum and fluoroplastic to the molar masses of aluminum and fluoroplastic:

$$N_{\text{Al}} = \frac{m_{\text{Al}}}{M(\text{Al})}; N_{\text{Ft}} = \frac{m_{\text{Ft}}}{M(\text{Ft})} \quad (15)$$

To determine the heat released during the passage of a chemical reaction, select the smallest number of moles of substances (fluoroplastic or aluminum) that can react and multiply this value by the amount of reaction heat calculated by thermochemistry methods:

$$E_{\text{react}} = N_{\min(Al/Ft)} \cdot q \quad (16)$$

The amount of caloric spent on heating the fuel to the self-ignition temperature is:

$$Q = C \cdot m \cdot (t_2 - t_1) \quad (17)$$

where t_1 – initial temperature (20 °C);
 t_2 – self-ignition temperature of DF;
 C – average specific heat for temperature range;
 m – mass of the DF (1 g).

To determine the effectiveness of the incendiary effect of assemblies No. 1 and No. 2, we define the mass of diesel fuel brought to ignition as:

$$m_{iDF} = E_{st} / Q \quad (18)$$

The results of the calculations are presented in Figures 4 and 5.

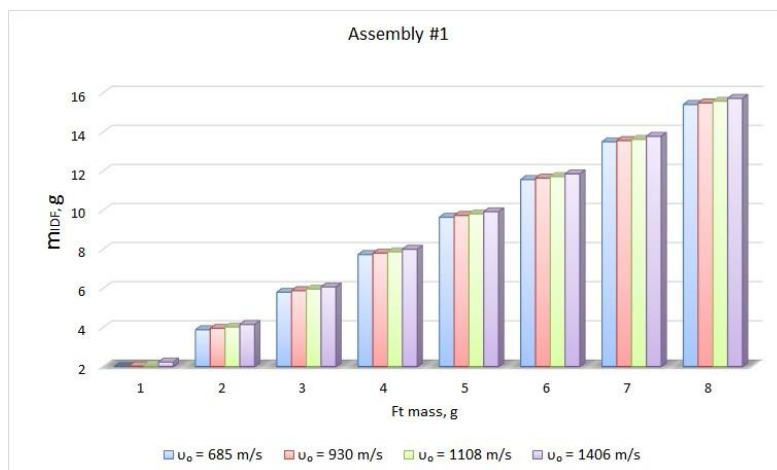


Figure 4. The mass of ignited DF depending on the mass of Ft in assembly No. 1.

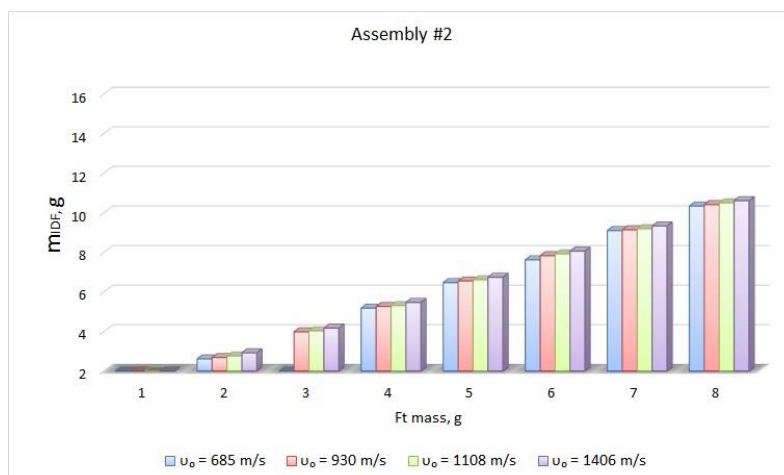


Figure 5. The mass of ignited DF depending on the mass of Ft in assembly No. 2.

The obtained results of calculations on the possible weight of ignited diesel fuel are in good agreement with the results of experiments that show steady ignition and combustion of fuel under the influence of the presented assemblies of strikers.

4. Conclusions

Studies have shown that under dynamic loading fluoropolymers can release enough energy to heat a certain amount of fuel to ignition temperature, which with a high degree of probability will lead to the ignition of all fuel in the tank. Thus, creating combined striker elements, including fluoroplastic, aluminum or titanium, along with an impact-penetrating effect sufficient to defeat thin-walled targets, will have a high inflammatory prohibitive effect.

Conducted studies on the ignition of one of the most resistant to ignition fuels - diesel fuel, gives the right to assume that light with high octane fuel used in aviation will ignite at lower interaction speeds. But at the same time, the speed of interaction should still be higher than the critical speed of the beginning of a chemical reaction between the fluoroplastic and aluminum or titanium.

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